ECOLOGY, ECONOMICS AND TECHNOLOGICAL DEVELOPMENT: A SOCIOCYBERNETIC PERSPECTIVE

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For more than two years faculty in the Colleges of Engineering, Natural Science, and Agriculture and Natural Resources at Michigan State University have been "working partners" in a research effort entitled "Ecosystem Design and Management", under the support of the RANN Section of the National Science Foundation. The overall central objective of this effort is to advance the scientific and technical base for ecologically and sociologically sound planning for technological development and regional economic growth.

The insights and understandings gained through these efforts suggest major new responsibilities in agricultural development and economic pricing policy. Many of these responsibilities relate directly to the laws of material and energy balance which govern the interactions between agricultural production processes and other parts of our life-support system as a closed ecological system. Other responsibilities relate to the potential sociological implications of some of the present trends in agricultural production.

The pages following attempt to highlight these sensitivities and responsibilities as seen through a sociocybernetic model of human life-support. Some of the basic principles of ecosystem design and regulation are presented along with the direction they provide in structuring coordinated programs of research and development to deal with important aspects of these new responsibilities.

THE HUMAN LIFE-SUPPORT SYSTEM AND ITS SOCIOCYBERNETIC CONTROL

The structural features of a model characterizing the process of life support are illustrated in Figure 1. This model consists of three major subsystems: (a) the physical environment as the ecological base of our production, consumption and recreational processes, (b) the system of production and consumption processes, and (c) the cybernetic regulatory and control processes. These subsystems and their interaction can be summarized as follows, Koenig and Tummala (1972).

The essence of the life-support system is a set of interconnected transformations on the structural state of materials, their spatial transportation, and their physical and biological storage. Physical, solar, and human forms of energy are required to carry out each of the processes in industry and agriculture according to known physical and biological laws. The laws of material and energy balance govern the interaction of the components as a closed ecological process.

Each component of the natural environment (each lake, stream, airshed, coastal region, etc.) has a limited capacity to process indentifiable classes of materials and energy discharged as wastes from the life-support processes. These capacities are *regionally specific* and they depend upon the "quality" of the environmental component to be maintained; quality being a subjective judgement.

The "effectiveness" of the life-support system in providing the physical needs and wants of man is determined ultimately by the *mass-energy* characteristics of the system, the availability of the requisite forms of energy to drive it, and the temporal stability and reliability of the functional system as a whole.

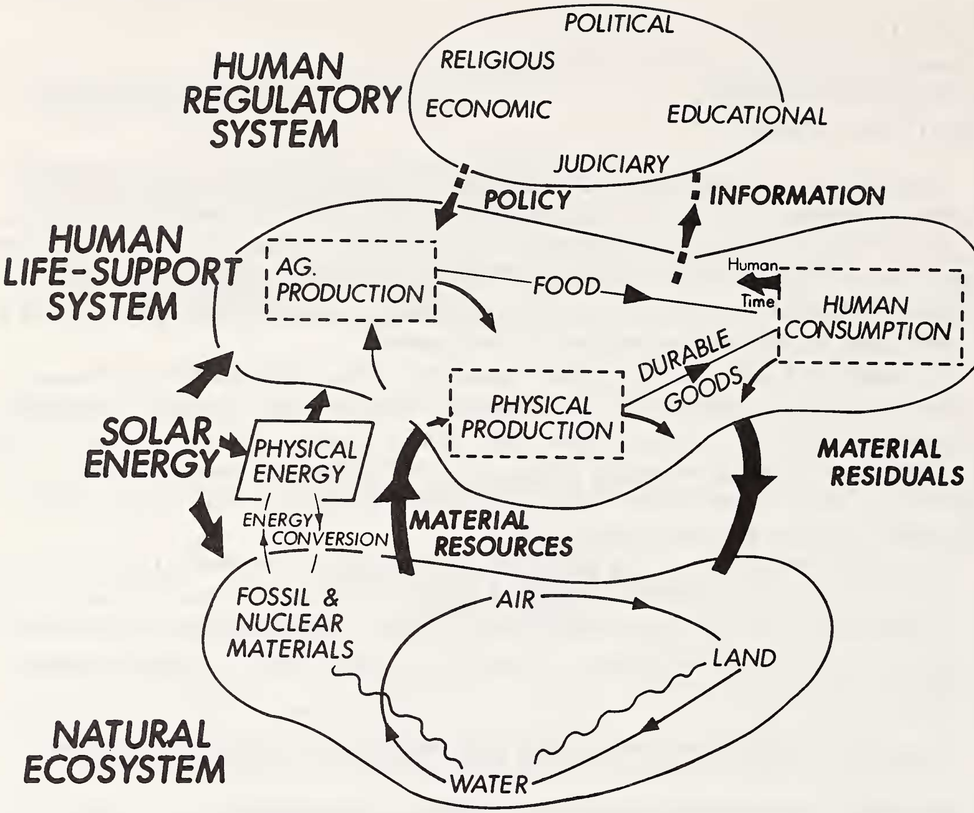

Fig. 1. A model for the human life-support system and its sociocybernetic control.

The physical and technological structure[1] of the life-support system serves essentially as a "template" to which social, cultural, and service activities adjust through homeostatic or self-adaptive processes. To this extent, the potential for individual human and cultural fulfillment is deeply rooted in the physical and technological structure of the system. Indeed, the physical structure of the life-support system is the "house" in which man lives, works, and recreates on the surface of the earth.

Two general modes of dynamic behavior of the life-support system must be distinguished: (1) the short-term *mass-energy dynamics* of the life-support system and (2) long-term *successional changes* in its technological and physical structure. The first mode of behavior has to do with the temporal and spatial changes in the flow rates of material and energy for an essentially

1 Physical structure includes all aspects of technological form and spatial distribution and location of the production processes, transportation, and human habitat. The degree of spatial centralization and specialization of processes is an aspect of physical structure of particular concern.

fixed physical structure. The second deals with temporal changes in the technological form and physical structure. The two modes can be distinguished, in part, by time constants that differ by orders of magnitude. Both modes are regulated by a variety of man-made social instruments of control, including in particular the economic system.

In principle all social decision making processes should act on the information provided by the "sensors"; the information in turn specifying the state of the life-support system. Effective and flexible socio-political mechanisms must contain a variety of separate but coordinated decision making mechanisms with a corresponding spectrum of time constants and effectors for transmitting the instruction of the decision making mechanism back to the life-support system as *policies.* The specific mechanisms selected depend on the choice of the behavioral variables in the life-support system to which the effectors are to be coupled, and through which the control is to be exerted. The choice of these is, in part, a technical matter governed by the objective dynamic properties of the controlled system and in part a matter for social, economic, and political judgments. But it cannot be too strongly emphasized that the precise mechanisms by which the decisions in these sociocybernetic control loops are to be made need not, and indeed cannot, be characterized in advance, except to note that certain general constraints (e.g., involving time delays, reliability, and compatibility with the controlled system) must be an essential part of its design.

From this sociocybernetic perspective the problems of technological planning and regional economic developments are essentially those of the control of the short-term and long-term dynamics of a *physical* system (the life-support system) by collective man (i.e., by society). The crucial questions are:

(1) What family of states of the controlled system are most desirable, or, alternatively, what family of states are to be avoided?

(2) Given this information, what kinds of social instruments are required to carry out the essential functions of control and how shall they be deployed?

These questions involve a mixture of purely technical matters, which may be decided purely on the grounds of science and technology, and matters which are intrinsically extra-scientific. The sociocybernetic perspective recognizes this situation and provides a framework through which purely technical, scientific inputs may be given their full weight without encroaching on those aspects of the problem which fall outside its domain. Within this framework it is the responsibility of science and engineering to (a) specify, and where possible, solve, the purely scientific, system-theoretic questions relating to the mass-energy characteristics obtainable from life-support systems having alternative physical and technological structural features – a concept of ecosystem design[2], and (b) in those situations intrinsically involving collective societal judgments, to provide a sound characterization of those alternatives or options open to society, so that an informed judgment may be made – a concept of ecosystem management.

Solutions to the scientific, systems-theoretic questions and assessment of alternatives involves looking at the overall life-support system from a variety of perspectives and levels of organization, each with its own degree of resolution, time horizons, and specific questions. At one end of this spectrum we have theoretical studies of the general mass-energy and economic characteristics of the life-support system as an abstract material-processing "machine" constrained in its design and operation by the physical and ecological limits of the environment. At the other end we have more specific indepth problems dealing with the quantitative analysis and design of the detailed microstructure of an agricultural or industrial production

2. The word ecosystem is used here in a somewhat more inclusive sense than usual, to refer to man *with* his natural environment.

process, an urban community, or a lake or stream as real-world components of the total life-support system. It is largely at this latter end of the spectrum that the "cutting edge" of action is generated. But developments in sound theoretical foundations and basic principles of overall design and management of our total life-support system as a closed ecological process are the essential elements of the evolving science which directs, integrates, and coordinates these more detailed cutting-edge activities into something more than a random set of disjoint activities. Some of these basic principles have already begun to emerge and are worth identifying for the perspective and direction they provide for more detailed lower level studies.

BASIC PRINCIPLES OF DESIGN AND REGULATION

Ecological Constraints

The mass-energy processing capacities of natural environmental components clearly stand as physical limitations or specifications to which the technological processes in industry, agriculture, and the human habitat must be designed for long-term compatibility with counterpart processes in the natural environment. They stand as unremovable physical constraints on regional developments, population densities and distributions, and technological activity. The family of states that are not ecologically feasible in this sense must be avoided. But to avoid them we must know explicitly the time – space capacities of the various components of the environment (lakes, streams, coastal regions, airsheds, etc.) to process specific classes of materials (heavy metals, oxides of sulfur, organic compounds, etc.) as a function of the "quality" (ecological state) to be maintained in the environmental component. The very magnitude and complexity of this class of problems alone raise scientific and institutional questions of the greatest importance, but for which the scientific base is as yet extremely limited.

Social and cultural considerations in general impose additional constraints on the class of allowable states, which may be more restrictive than ecological constraints. Some of these considerations are discussed by Koenig *et.al.* (1972) but the scientific literature on the subject is virtually nonexistent. Investigation of these questions is not yet an established area of research in the social sciences and it is not clear to what extent such constraints can be quantified or the major factors even identified. Most social and cultural considerations must, therefore, be regarded as extra-scientific, at least for the present. In principle they must be dealt with on a subjective basis as part of the decision process in the sociocybernetic control loops.

Physical and Technological Structure

From the laws of material and energy balance and the regional-specific and material-specific processing capabilities of the natural environment, it follows that long-term ecological feasibility can only be achieved by coordinating two basic structural features: (a) technological recycling[3] of materials and (b) spatial distribution of industrial, agricultural, and human habitats according to the regional-specific waste processing capacities of the natural environment. Since the capacity of the environment to process certain classes of materials (such as heavy metals) is virtually zero and since the technology for recycling of other classes of materials is not available or it is not feasible to implement, ecological campatibility *cannot* be achieved by recycling alone or by spatial distribution alone. Further, where technological and natural environmental processing of material and thermal wastes exist as technically feasible alternatives, they must be recognized as socio-economic options.

3. Technological recycling as used here includes all forms of physical processing, including inert storage for future "remaining."

It follows from the general properties of the physical laws of material production that energy requirements and the waste processing "load" placed on the natural environment increase roughly in direct proportion to the flow *rates* of all species (types) of products delivered to man. The general well-being of man depends upon the flow rates of food species *and* upon the standing *stocks* of durable species (clothing, automobiles, houses, etc.). Consequently, the state of well-being of man in a finite world increases as the life-expectancy of durable products is increased.[4]

As simple as these principles are, the physical and technological structure of our present life-support system is a complete contradiction of them. It is basically a "once through" system and it is highly centralized and specialized spatially with respect to industrial production, agricultural production, and human consumption. It is regulated by a "growth economy" that measures standard of living by an inadequate method (GNP measures activity only, not standing stocks) and it stimulates increased material flow rates through consumerism, throwaway products, and built-in obsolescence.

Regulatory Aspects

Given this present physical and technological state of our life-support system, the critical question is what adjustments or new developments in social instruments of control are required to bring the system within a class of structures that are ecologically feasible in the long term or at least to reduce some of the regional environmental stresses. A closely related question of equal critical importance is, can this be done in such a way as to simultaneously relieve rather than compound the many sociological stresses that are increasingly evident in the day-to-day events of modern life. Comprehensive answers to these questions raise economic, social, and political issues of the greatest possible importance.

Perhaps a first step in attempting to answer these questions it is helpful to recognize that the existing instruments of control, ranging from the life style and behavioral patterns of the individual participants in society to the economic system itself, were formed at a time when technology was a limiting factor, i.e., at a time when we did not have the industrial capability to seriously overtax the limited reserves of the geosphere or to overdrive the limited capacities of regional environments. As a result, virtually all instruments of regulation and virtually all social attitudes were found without benefits of an ecological perspective. The development of new levels of understanding of the limitations imposed on a highly advanced technological society by the laws of material and energy balance is clearly an important and critical element of change in all social instruments of control. But beyond this there is increasing evidence that the economic system itself is one instrument, if not the most effective, for controlling the successional dynamics of the life-support system, i.e., the sequential changes in the physical and the technological structure.

The concepts of successional dynamics, successional stability, and climax states are central to the theory of natural ecosystems. There is much to suggest that these same concepts are also central to ecologically and sociologically sound economic and regulatory policy. It is possible to gain some insight into these questions from a careful study of the mass-energy and economic characteristics of a static model of the life-support system (Koenig and Tummala, 1972).

4. An electric power company whose connected load is predominantly automotive industry (70%) estimates, for example, that if the life expectancy of the American car were doubled (a technically feasible objective) the company would not be required to expand generating capacity for about 10 years. It should be noted, however, that in the face of potentially new developments in technology one may not choose to maximize the life expectancy of some durable species.

Through the economic system we associate a monetary value with each material flow in the life-support system, including the material exchange rates with the environment. These monetary values (whatever they are – zero or nonzero) form the basis for at least one major component of a countless number of priority decisions by individuals and groups of individuals at all levels of social organization. Insofar as the technological and physical structure of the life-support system is concerned, the economy can therefore be regarded as a regulatory mechanism. The monetary values associated with the material exchange rates serve as the weighting "signals" used by the engineer, the developer, the businessman, the farmer, and all other social decision making units in assessing their "value functions," whether these value functions are definable mathematically or not. One of the fundamental difficulties, if indeed not *the* fundamental inconsistency of present pricing mechanisms in our economy, is that they are based on the precept that the regional limitations of the environment for processing wastes are unbounded. The monetary costs, for example, now assigned to the materials discharged into the natural environment are all taken as zero, and costs assigned to materials extracted from the geosphere are based on short-term opportunities rather than long-term ecological considerations. The economy as a cybernetic control process is manipulating successional changes in structure that are not ecologically sound because it is receiving the wrong weighting signals. In less abstract terms, the day-to-day economic feasibility analyses made by engineers and others in the context of their individual problems simply do not include all the important socioecological factors, and the rules of economic survival were not designed for a game of life in a finite world with a highly sophisticated technology.

Modern technology has greatly expanded the scale economies to human forms of energy (labor) in both physical and agricultural production through automation and large-scale mechanization. In general, modern computers extend these scale economies further through the mechanization of the management function of the firm. It can be anticipated that new technological innovations will extend these scale economies beyond the present range. From the structure of the material and energy balance model of the life-support system it follows that successional change toward centralization and specialization will persist as long as competition and decision making at the firm level are dominated by monotonically increasing scale economies (Koenig and Tummala, 1972). If the scale economies are strictly increasing, the system will not have a favorable climax state.[5] The scale of mechanization in agriculture has already progressed to the point where only 4.8 percent of the Nation's working population is involved in agricultural production. Under the present trends it is projected that this number will drop considerably below this figure. In relationship to industrial production it can be noted that 20 years ago half of the physical productive capability in the United States was controlled by 200 firms (Anon., 1971). Today half of the productive capability is in the control of 100 firms. Under present trends the number of people involved in physical production is expected to drop to about 13 percent of the working population.

The central impact of technology on society appears to be this: The economic forces of competition generated by a highly advanced technology in the context of present economic price mechanisms is creating successional changes toward what appears to be essentially "unbounded" concentration, specialization, and centralization of production processes. Since the physical structure of the life-support system serves as the superstructure for many of the service, social, and cultural activities of man, these successional changes are generating unbalanced spatial distribution of population, spatial concentrations of waste, extreme job specialization

5. In reality social forces other than economies will eventually bring about a climax state which may or may not be orderly.

and work activity, and centralized control of production facilities. Large-scale mechanization and specialization in agriculture have a particularly profound impact on the spatial distribution of people and the distribution of organic wastes. In a sociological context one must ask what percentage of the population would prefer to be engaged in agriculture production? Is it 2 percent or 20 percent? Can a society with only 13 percent of its working population involved in physical production provide meaningful work activity for all of its people? At what point does leisure time become socially degenerating idle time?

A highly specialized and centralized system provides efficient uses of human energy, and it is precisely this improved efficiency that generates leisure time and an opportunity to pursue cultural goals. But, apparently the physical limitations of regional environments impose an upper bound on how far man can go in exploiting these scale economies to human energy. To a degree these physical limitations are a function of the extent to which material recycling is feasible and clean sources of physical energy are available. However, social stresses implicit in the excessive concentration of people, specialization, accumulated control of production capacity, job specialization, and centralized decision making must be addressed in different fashions than those appropriate for the material constraints.

Finally, in reference to the impact of technology on the problems of social regulation, some of the most important questions of sociocybernetics control center around the relationship between the degree of centralization in the control process and the level of specialization and centralization of the control object (the life-support system). The problems of identifying effective, responsive, coordinated, and reliable social instruments of management in themselves apparently place an upper bound on the degree of centralization and specialization in the physical structure of the life-support system that can be tolerated. These bounds may be more restrictive on the physical structure than the constraints imposed by ecological and sociological considerations. The dominant limitations apparently are to be found in the problems of decision reliability and interinstitutional compatibility, the information required to support them, and the time delay involved in their implementation. Wrong decisions or correct decisions with excessive temporal delays can and do lead to regenerate feedback and unstable loops within the system. Two contemporary examples illustrate these points:

(1) The "time honored" strategy of the Government of the United States to deal with the problems of unemployment has been to stimulate economic expansion through the construction of new production facilities and promotion of new products. The business community augments this strategy by promoting obsolescence and consumerism. The combined result in general speeds up the production machinery. Increased flow rates in the system not only increase the waste processing requirements of the environment and the physical energy requirements, but they make increased specialization, centralization, and automation economically feasible with a subsequent cycle of unemployment.

(2) The population of rural America displaced by large-scale mechanization in agriculture moves to large urban areas (approximately 20 million in 20 years) with employment expectations that appear to be essentially proportional to the size of the physical production complex of the urban community. The urban planner, the Chamber of Commerce, and other well-meaning organizations, on the other hand, attempt to provide job opportunities for the unemployed by promoting further industrial expansion in the urban community. The industrial expansion in turn raises the employment expectations and with it increased migration to the large urban community. The whole process is a regenerative spiral with no apparent equilibrium point.

It can be shown that, in principle, the evolution of technological and physical structure of the human life-support system can be constrained within an ecologically feasible class of structures through the monetary costs assigned to the material exchange rates with the natural environment (Koenig and Tummala, 1972). In general, the monetary costs assigned to these exchange rates must increase exponentially as the steady-state material processing capacity of the *recipient* environmental component is approached. Such costs in effect reflect environmental diseconomies as the threshold of capacity is approached. Under such pricing mechanisms it can be shown that successional changes in the structure of the life-support system will theoretically approach an ecologically feasible climax state.

But there are many practical difficulties in implementing such pricing mechanisms. Some of the practical difficulties inherent in the direct application of such pricing mechanisms to the environmental exchange rates can be overcome by indirect application. For example, since for any given product species and production technology the waste discharge rates into the environment are essentially proportional to the production rates (outputs), the same objective can be realized (perhaps with relatively minor loss of precision) by non-uniform taxes levied against the productive capacity (output) of the processing unit. Such taxes must vary with product species, the production technology used to produce the species, and the productive capacity of the unit. In agriculture such pricing policies reduce essentially to the simple concept of tax on agricultural production land that is specific to the type of production technology in use, but graduated with respect to the potential productive *capacity* (size) of the unit; the rate of graduation being based on ecological and sociological considerations rather than "pollution damage" as such.

It can also be shown that uniform environmental standards (physical regulations) on waste discharge rates imposed on the polluter *cannot* regulate successional changes (Koenig and Tummala, 1972). In fact, such policies will force centralization in the context of present pricing mechanisms. It is easy to show that uniform standards on SO_2, for example, are counter-productive in the successional dynamics they produce – technological removal is economically feasible under present pricing structures only for large scale centralized operations. As a basic principle, it is critical to recognize that economic and physical regulations that are uniform with respect to material rates and spatial regions *cannot* regulate successional changes in the spatial distribution of production processes or their scale of operation (centralization and specialization).

Given the complexity and the apparent high level of interdependence between changes in the short-term mass-energy characteristics and the longer-term successional changes in physical and technological structure, it can be stated with almost complete assurance that effective regulation of the temporal dynamics of our life-support system cannot be achieved through the implementation of any one policy, or even a combination of policies directed at a single goal. For example, it would be most difficult indeed to realize increased life expectancies of major durable products in the United States in the face of present unemployment problems. However, if such a goal is coordinated with simultaneous moves toward an electrically based economy[6] and decentralization as national goals, it may be entirely feasible. Modern control theory and cybernetics have a lot to offer in the conceptual and theoretical aspects of such control problems. But the kinds of problems which have been dealt with effectively with these concepts and theories have not, in general, involved major human and social dimensions. Therefore,

6. Given recent estimates of petroleum and fossil fuel (see, for example, Starr, Scientific American, Sept. 1971, pp. 37-49), there is little question but what the economy of this Nation must be converted from a petroleum base to a nonpetroleum base within the next several decades. From an ecological point of view, in the interest of minimizing the dangers of international conflict, and in the interest of preserving critical nonrenewable resources for future generations, the sooner such a conversion can take place the better.

although the field of cybernetics may give general strategic indications of how to proceed, corresponding tactics must be invented essentially *de novo.*

CONCLUSION

The sociocybernetic perspective discussed above points to many deep and important problems of major national significance which are directly or indirectly related to the physical and technological structure of our life-support system and the economic forces that largely direct its trajectory of successional development. There appears to be increasing evidence that the basic issues center about the tradeoffs among the ecological, sociological, and manpower efficiency factors of a highly centralized and specialized life-support system in relationship to more decentralized, diversified system. The scale of mechanization (size of the operating unit) and the degree of product specialization in agriculture apparently have particularly profound effects on both ecological and sociological factors. At what point on the trajectory of current development should centralization and specialization be curtailed for ecological and/or sociological reasons; or has the successional development already progressed irreversibly in this direction?

To be sure, there is no simple, universal, time-independent answer to these questions across all product species, geographic regions, or production technologies, and they include many elements that are extrascientific in nature. Responsible scientific inputs to these questions will require that the tradeoff be evaluated in relationship to classes of product species and geographic regions to account for both spatial variations in environmental capacities and product-specific technologies. As one small initial step in this direction, the program of research out of which this paper is developed selected freshwater lakes and streams and terrestrial irrigation of urban and animal wastes as prototype studies for evaluating the mass-energy rate capacities of regionally specific environmental components. Power plant site design and beef production in agriculture were chosen as prototypes of the general problem of integrating industrial and agricultural processes into pre-existing ecosystems and for evaluating explicitly the economic, ecological, and sociological tradeoff implicit in scales of mechanization and levels of diversification. Control of cereal-leaf beetle damage in cereal grain production through integrated strategies in parasitation, crop phasing, and insecticide application was selected as a prototype problem in the design and sociocybernetic control of seminatural ecological process. The specific goals and research strategies in each area are designed to answer specific questions relating to the general principles outlined in the previous section.

But these efforts at best only identify the "tip of an iceberg" of research and development necessary to bring the life-support processes of a highly advanced technological society into harmony with our natural environment and our sociological needs and values. The very magnitude and complexity of this problem raises methodological questions of the greatest importance. But it can be safely asserted that we have arrived at a point in the history of industrial development where, by sheer weight in numbers and technological power, we can and do significantly affect regional environmental components that in the long run are as much an integral part of man's existence and state of well-being as food and shelter. It is fundamental to this new point in history that economic pricing policy acknowledge the unremovable laws of material and energy balance that govern our ecological existence, and that the fundamental sociological and ecological issues of our time can no longer be dealt with through minor perturbations on existing scientific research and institutional policies. They require a quantum jump in conceptual understandings, goals and methodological approaches in the physical, biological and social sciences and engineering.

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